Glulam Design for Fire Performance
膠合集成材設計之防火表現

Taipei
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APA – The Engineered Wood Association

Taiwan Fire Code

- Fire Code for Wood Construction in Taiwan (木構造建築物設計及施工技術規第九章建築物之防火) was published in November 2008
- Dr. Su (蘇鴻奇) presented background info at the last APA Seminar in August 2008

Characteristics of Glulam in Fire

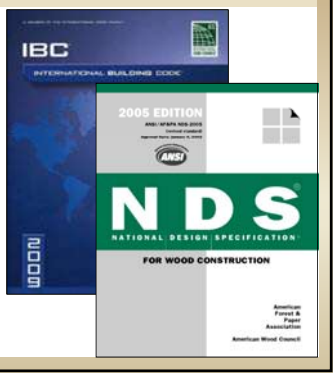
- Wood is an excellent heat insulator
- Develops a char layer after fire exposure
- Self-extinguishing after fire source removed
- Retains significant residual strength after being exposed to fire

Glulam vs. Steel

Glulam vs. Steel

Fire Rating for Glulam

- Two accepted methods under US Building Codes
  - IBC Empirical Method
  - NDS Mechanics Based Model



APA Technical Note

- Provides details of the IBC and NDS methods
- Examples for both methods

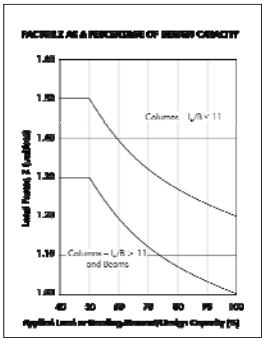
IBC Methodology

- Empirical protocol
- Based on extensive testing in the U.S. and other countries using the ISO 834 fire test protocol
- Beams – 3 or 4 sides exposed
- Columns – 3 or 4 sides exposed

IBC Methodology for Beams

- **Beams exposed on 3 sides**
  t = 2.54ZB [4 – B/D]
- **Beams exposed on 4 sides**
  t = 2.54ZB [4 – 2B/D]
  - **B = beam width**
  - **D = beam depth**
  - **t = fire resistance in minutes**
  - **Z = load compensation factor**
    = applied load / design capacity

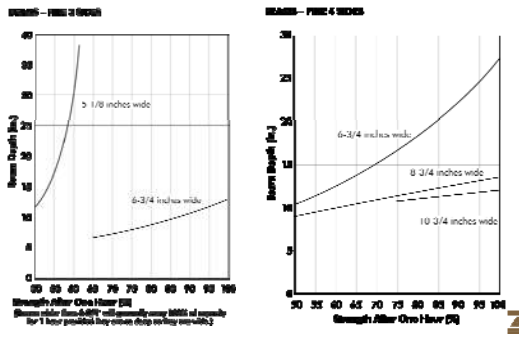
IBC Methodology



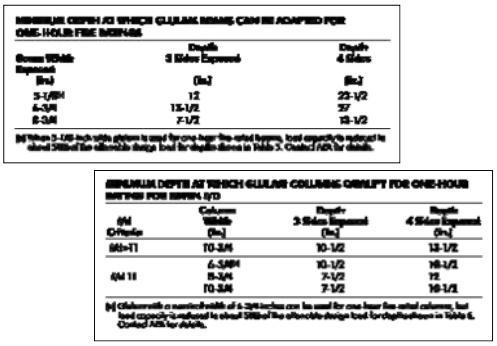
IBC Methodology for Columns

- **Columns exposed on 3 sides**
  t = 2.54ZB [3 – B/2D]
- **Columns exposed on 4 sides**
  t = 2.54ZB [3 – B/D]

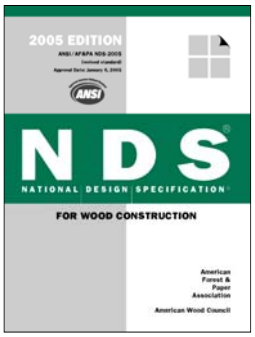
One-Hour Fire Rated Glulam



One-Hour Fire Rated Glulam



2005 NDS Methodology



- Chapter 16
- Mechanics Based Model
- Supported by empirical data

2005 NDS Methodology

- Determine reduced section properties of glulam after fire exposure using effective char layer
- Calculate induced bending stress with reduced section
- Determine the member strength based on tabulated stress x fire adjustment factor (2.85 for bending)
- F_b x 2.85 ≥ calculated induced stress

2005 NDS Methodology

			ASD					
			Design Stress to Member Strength Factor	Size Factor	Volume Factor	Flat Use Factor	Beam Stability Factor	Column Stability Factor
Bending Strength	F_b	x	2.85	C_F	C_V	C_{fu}	C_L	-
Tensile Strength	F_t	x	2.85	C_F	-	-	-	-
Compression Strength	F_c	x	2.58	C_F	-	-	-	C_P
Beam Buckling Strength	F_{bE}	x	2.03	-	-	-	-	-
Column Buckling Strength	F_{cE}	x	2.03	-	-	-	-	-

- The strength factor brings the fire design to the average breaking strength of glulam

2005 NDS Methodology

$$\beta_{eff} = \frac{1.2\beta_n}{t^{0.187}}$$

Where:

β_{eff} = Effective char rate (in./hr), adjusted for exposure time, t

β_n = Nominal char rate (1.5 in./hr)

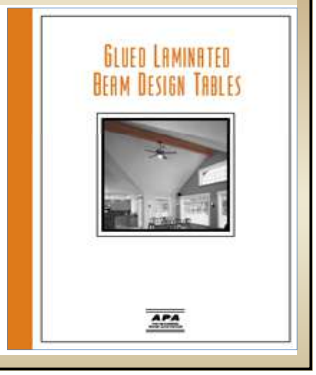
t = Exposure time (hr)

2005 NDS Methodology

t	β_{eff}
1 hr	1.8 in./hr (45.7 mm/hr)
2 hr	1.58 in./hr (40.1 mm/hr)

IBC Example: Glulam Beam

- EWS S475 Glulam Design Tables



IBC Example: Glulam Beam

- L = 30 ft simple-span
- TL = 240 lbf/ft (dead + snow load)
- 3-side exposure
- F_b = 2,400 psi
- E = 1.8 x 10^6 psi
- F_v = 265 psi
- Determine 1-hr fire rated glulam

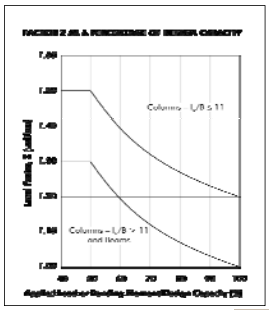
5-1/8-INCH WIDTH — SPAN (ft)

Depth (in.)	8	10	12	14	16	18	20	22	24	26	28	30
12	3829	2445	1693	1240	946	660	477	355	270	209	164	131
13-1/2	4848	3097	2145	1572	1199	944	684	509	389	302	238	191
15	5987	3825	2651	1942	1483	1160	926	703	537	419	332	266
16-1/2	7093	4630	3209	2352	1788	1392	1111	906	720	562	446	358
18	8126	5513	3821	2802	2111	1644	1313	1071	888	733	583	470
19-1/2	9268	6472	4487	3264	2460	1915	1530	1248	1036	872	743	601
21	10537	7287	5206	3759	2833	2207	1763	1439	1194	1005	857	738
22-1/2	11955	8121	5937	4287	3232	2518	2012	1642	1363	1148	979	843
24	13551	9024	6713	4848	3655	2848	2277	1858	1543	1300	1108	954
25-1/2	15340	10007	7416	5442	4103	3197	2556	2087	1733	1460	1245	1073
27	17428	11078	8115	6068	4576	3566	2851	2328	1934	1629	1390	1198
28-1/2	19814	12252	8863	6726	5073	3953	3162	2582	2145	1807	1542	1329
30	22598	13544	9664	7416	5594	4360	3487	2848	2366	1994	1701	1467
31-1/2	25889	14972	10524	8110	6139	4785	3827	3126	2597	2189	1868	1611
33	28892	16558	11451	8747	6708	5229	4183	3417	2839	2394	2043	1762

IBC Example: Glulam Beam

- Try 5-1/8" x 21" (allowable = 266 plf)
- 240 / 266 = 0.90
- Z = 1.03
- t = 2.54 x 1.03 x 5-1/8 x (4 – 5-1/8 / 15) = 49 min.

NG!



IBC Example: Glulam Beam

- From design table, choose 5-1/8" x 18" (allowable = 470 plf)

5-1/8-INCH WIDTH												SPAN (ft)
Depth (in.)	8	10	12	14	16	18	20	22	24	26	28	30
12	3829	2445	1693	1240	946	660	477	355	270	209	164	131
13-1/2	4848	3097	2145	1572	1199	944	684	509	389	302	238	191
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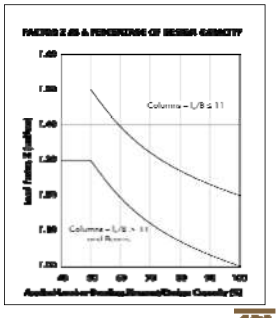
33	28992	16558	11451	8747	6708	5229	4183	3417	2839	2394	2043	1762

IBC Example: Glulam Beam

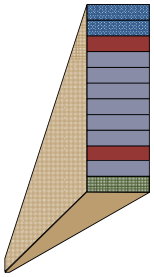
- 240 / 470 = 0.51
- Z = 1.28
- t = 2.54 x 1.28 x 5-1/8 x (4 – 5-1/8 / 18) = 61.9 min.

OK!



Typical Glulam Beam Layup

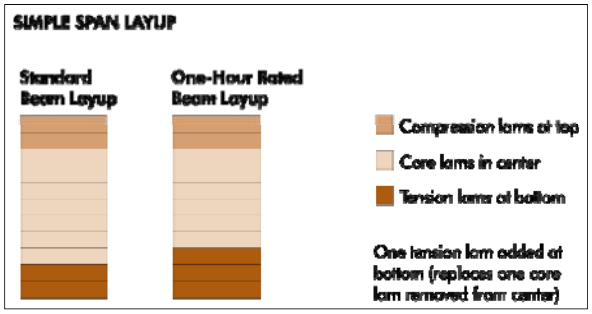
24F-V4 Doug Fir (12 Lamination Example)



- 2 - L2 Dense Grade Outer Comp. Lams
- 1 - L2 Grade Inner Comp. Lam
- 6 - L3 Grade Core Lams
- 1 - L2 Grade Inner Ten. Lam
- 1- L1 Grade Outer Tension Lams
- 1- 302-24 Outer Tension Lams

For 1-hour fire rated beam: substitute additional tension lam for core lam

Fire Rated Glulam Layup



NDS Example: Glulam Beam

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- TL = 240 lbf/ft (dead + snow load)
- 3-side exposure
- F_b = 2,400 psi
- E = 1.8 x 10^6 psi
- F_v = 265 psi
- Determine 1-hr fire rated glulam

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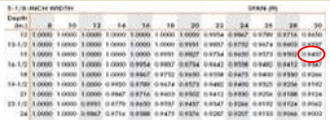
33	28892	16558	11451	8747	6708	5229	4183	3417	2839	2394	2043	1762

NDS Example: Glulam Beam

- Try 5-1/8" x 15"
- For 1 hr fire rating, β_{eff} = 1.8 in./hr
- $b_{1\text{-hr}}$ = 5-1/8" – 2 x 1.8" = 1.525"
- $h_{1\text{-hr}}$ = 15" – 1.8" = 13.2"
- $S_{1\text{-hr}}$ = 1.525 x $13.2^2/6$ = 44.3 $in.^3$
- $M_{1\text{-hr}}$ = 2.85 x F_b' x $S_{1\text{-hr}}$ = 2.85 x 2, 400 x 0.9437 x 44.3 / 12 = 23,831 lbf-ft



NDS Example: Glulam Beam

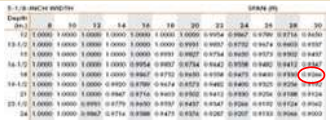
- $M_{applied}$ = $wL^2/8$ = (240 + 18.7) x 30^2 / 8 =29,102 lbf-ft > $M_{1\text{-hr}}$ (23,831 lbf-ft)

NG!

5-1/8-INCH WIDTH

Depth (in.)	12	13-1/2	15
Beam Weight (lb/ft)	14.9	16.8	18.7
A ($in.^2$)	61.50	69.19	76.88
S ($in.^3$)	123.0	155.7	192.2
I ($in.^4$)	738.0	1051	1441

NDS Example: Glulam Beam



- Try 5-1/8" x 18"
- For 1 hr fire rating, β_{eff} = 1.8 in./hr
- $b_{1\text{-hr}}$ = 5-1/8" – 2 x 1.8" = 1.525"
- $h_{1\text{-hr}}$ = 18" – 1.8" = 16.2"
- $S_{1\text{-hr}}$ = 1.525 x $16.2^2/6$ = 66.7 $in.^3$
- $M_{1\text{-hr}}$ = 2.85 x F_b' x $S_{1\text{-hr}}$ = 2.85 x 2, 400 x 0.9266 x 66.7 / 12 = 35,213 lbf-ft

NDS Example: Glulam Beam

- $M_{applied}$ = $wL^2/8$ = (240 + 22.4) x 30^2 / 8 =29,522 lbf-ft < $M_{1\text{-hr}}$ (35,213 lbf-ft)

OK!

5-1/8-INCH WIDTH

Depth (in.)	12	13-1/2	15	16-1/2	18
Beam Weight (lb/ft)	14.9	16.8	18.7	20.6	22.4
A ($in.^2$)	61.50	69.19	76.88	84.56	92.25
S ($in.^3$)	123.0	155.7	192.2	232.5	276.8
I ($in.^4$)	738.0	1051	1441	1919	2491

Example Summary

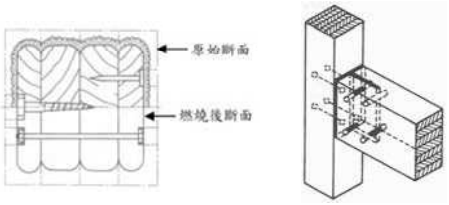
- The same example,
  - IBC = 5-1/8" x 18"
  - NDS = 5-1/8" x 18"

Connections

- 木構材接合部之設計應注意保護金屬扣件，避免火災持續燃燒期間因受火害之高溫影響，使金屬扣件強度衰減，導致接合功能之喪失。因此若使用金屬扣件接合時，應設置足夠厚度之防火被覆保護金屬扣件，或將接合金屬扣件設置在具防火時效之構材安全斷面內側

Connections

以金屬扣件連結之木接點應深入至防火時效後之殘餘斷面



Fire Safety of Light Frame Construction

Fire Safety of Light Frame Construction

Hybrid construction with 1st story of steel or concrete supporting 2-4 stories of wood framed construction

Light Frame Construction

- IBC permits calculation of fire performance based on component additive method
- Evaluated in accordance with ASTM E119 assembly tests
  - Wall assemblies
  - Floor assemblies
  - Roof assemblies

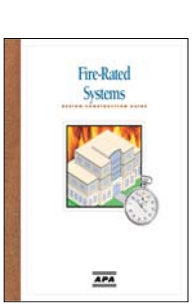
IBC Component Method *

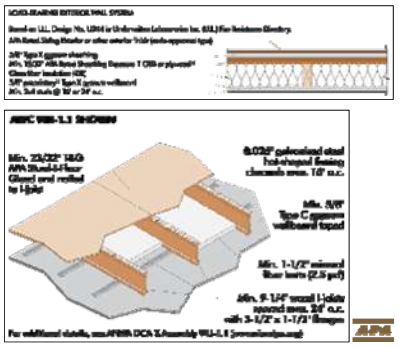
Example: Assume wood framed wall

2x4 studs at 16" on center	20
15/32" wood structural panel	10
1/2" gypsum wallboard	15
glass fiber wood batt insulation	15
Total =	60

* Section 721.6 of IBC
Fire-Resistance of Wood Assemblies

Fire Rated Systems





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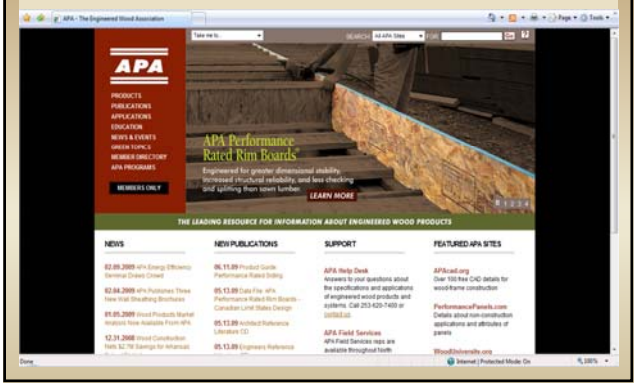
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